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Design and Fabrication of a Laboratory Scale Updraft Gasifier

ADEWUYI, A.S.; *LASISI, K.H.

Department of Civil Engineering, School of Engineering and Engineering Technology, Federal University of Technology, Akure, Nigeria
**Corresponding author Email: adew.steve@gmail.com; Tel: +2347033193609 senserltd@gmail.com;Tel: +2347032308193*

ABSTRACT: One major necessity for the existence of human beings is energy and biomass is one major source of energy especially in rural areas. This study presents a design, fabrication and performance evaluation of a laboratory scale updraft gasifier tested on wood as fuel. The wood was analyzed for its fuel characteristics. The results of the proximate analysis of the wood showed that the respective moisture content of 45.9% (dry basis) contains 50.9% fixed carbon, 85% of volatile matter and 20% of ash content. The higher heating value (HHV) and low heating value (LHV) are 8409.65 KJ/kg and 7807.45 KJ/kg. The result of ultimate analysis gives some elemental compositions, which are carbon (18.9%), hydrogen (2.74%), nitrogen (0.58%) and oxygen (11.88%). The performance evaluation carried out on the wood indicates that it is suitable as fuel for the fabricated updraft gasifier. This gasifier has been designed and fabricated to meet various energy demands from locally available materials and should be further develop for various applications of heating and electricity supply.

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The role of energy in the development process of a nation is well known. The rate of energy demand and supply has enormous impact on the socio-economic development, the living standard and overall quality of life of the population of a nation. Generally, population and economic growth result in an increase in the rate of energy demanded and consumed, this demand had led to an alternative energy source. Today, a variety of improvements as regarding development of mechanisms, design of innovative turbine designs and so on have been used by nations to meet their energy needs. The process of gasification is one of such methods (Ningbo *et al.,* 2012; Ojolo *et al.,* 2012). Gasification is a sustainable thermo-chemical conversion method that creates low levels of pollution, which converts solid and organic materials to a mixture of combustible gases by partial oxidation at elevated temperatures (500-1400°C) (Jenkins, 2010).

This conversion is cause by combusting a solid material (most often biomass components) with limited oxygen to produce an exhaust gas known as producer gas or synthesis gas. This technology is a robust proven technology that operate either as a simple, low technology system based on a fixed-bed gasifier, or as a more sophisticated system using fluidized-bed technology (Yadav *et al.,* 2013).

Biomass generally is use as energy source especially for remote areas where supply of high quality fossil fuels is not possible or costly. It is a central substitute energy basis. Energy generated from biomass act as main alternative energy source to luxurious energy assets. By use of burning and cleaning techniques, it can convert into an economical fuel (Imeh *et al.,* 2017). The properties of the biomass feedstock and its preparation are key design parameters when selecting gasifier systems and these systems can be built on any scale: small and simple for a single household or large and industrial for a whole municipality for commercial purposes. This study shows the design, construction and performance evaluation of an updraft gasifier using wood as a biomass material to serve as fuel (Tapash, 2012).

MATERIALS AND METHODS

The materials used in the design and fabrication of the updraft gasifier include AutoCAD software, MS pipes, MS rod, MS sheet, GI pipe, flat bar, union joint, elbow, gate valve, grate, nut, bolt, blower, glass wool, fireclay, Wood, Scale, Digital slide calipers and Tape. The components of the gasifier include the main gasifier unit (it has two cylinder pipes with 10 mm thickness, and inner diameter of 200 mm and 260 mm), blower (to supply air for combustion of fuel), grate, ash collector, ash outlet, gas outlet pipe, filter and chimney, etc.

Design Components: In designing laboratory scale gasifier, some parameters are considered as the paramount and can affect the outcome and subsequently the proper construction and performance of the system. They are

**Corresponding author Email: adew.steve@gmail.com; senserltd@gmail.com;Tel: +2347033193609*

Type of Reactor: The operating performance of the gasifier depends on the type of reactor used; the type under consideration is updraft reactor.

Cross-sectional Area of the Reactor: This is the area in which the wood fuels are burnt and this is where the fuel is gasified. The wider the cross-sectional area of the reactor, the more the gas produced.

Height of the Reactor: The height of the reactor determined the continuous operation time and the amount of gas produced for a fixed column reactor. Usually the combustion zone moves down the entire height of the gasifier reactor. The higher the reactor, however, the more pressure is needed to overcome the resistance exerted by the air compressor.

Thickness of the Fuel Bed: The thicker the layer of fuel in the reactor, the greater is the resistance required for the air to pass through the fuel column.

Insulation for the Reactor: The gasifier reactor was insulated with fiber glass to provide better conversion of the feedstock into gas and also prevent burning of skin when the reactor's surface is accidentally touched.

Construction Process of the Updraft Gasifier: The gasifier was constructed in stages. The reactor was initially constructed with two cylinders with height of 1000 mm and diameter (inner and outer) of 200 and 260 mm respectively. The thickness of the steel cylinders is 10 mm. The two cylindrical pipes were fixed with the help of flange plate (6 mm thickness and 400 mm diameter with an opening of 220 mm at the center) to adjust different in height between the pipes, the inner pipe was placed in the flange opening and welded at a distance of 600 mm from one end. It was thereafter inserted from the top of outer pipe with equal spacing and welded together (Plates 1a to 1c).

Where A = Cutting of flange plate; B = Flange welded with inner pipe; C = The outer and inner pipe forming the reactor; D = Attached air blower, E = Attached control valve, F = Fabricated grate; G = Fabricated ash collector, H = Fabricated filter I = Fabricated updraft gasify

Plate 1 (a to i): Construction stages of the updraft gasifier system

After the reactor has been fabricated, a 150 mm, AC operated blower, which has 1.6A, 110V, and 2500 rpm was fixed to supply air to the gasifier reactor through the pipe (Plate 1d). The air inlet pipe was set at 650 mm above the bed of the gasifier reactor. The blower will supply air into 19 mm diameter pipe made by GI pipe and a gate control valve was attached along the pipe to control the air velocity (Plate 1e). A grate made of iron rod with size 10 mm was placed at the bottom of the gasifier to act as air distributor (Plate 1f). During and after combustion, the fuel ash will falls through the grate and retain in the ash collector. After some cooling process, the ash outlet will be help dispose the ash from the collector. A gas outlet pipe of 19 mm diameter from the top of the gasifier filter was connected to the system. The gas exit delivery cone is 170 mm diameter. The size of pipe used to attain certain pressure drop and to reduce the velocity as well (Plate 1g). Elbow and universal joint were used to join the pipe that carries the produced gas to the designated point. A filter, which is cylindrical in shape with size 280 mm diameter and 300 mm height reduced to 250 mm of 90° bend with a control valve attached was finally attached (Plate 1h). Plate 1(i) shows the completely fabricated system used in the research work.

Design Parameters for the Operation of the Gasifier: The following parameters are used in evaluating the performance of the updraft-gasifier:

Start-Up Time (ST): This is the time required to ignite the fuel (wood) and consequently to produce combustible gas. This parameter is measured from the time the burning pieces of paper are introduced to the fuel in the reactor until combustible gas is produced at the burner.

Operating Time (OT): This is the duration from the time the gasifier produces a combustible
gas until no more gas is obtained from the burning feedstock.

Total Operating Time (TOT): This is the duration from the time fuel (woods) are ignited until no more combustible gas is produced in the in the gasifier. Basically, it is the sum of the start-up time and the operating time of the gasifier.

Fuel Consumption Rate (FCR): This is the weight of woods (fuel) used in operating the gasifier divided by the operating time. This is computed using Equation 1

$$FCR = \frac{Weight\ of\ the\ wood\ used\ (kg)}{Operating\ time\ (hr)} \quad (1)$$

Specific Gasification Rate (SGR): This is the amount of woods used per unit time per unit area of the reactor. This is computed using Equation 2

$$SRG = \frac{weight\ of\ the\ wood\ used\ (kg)}{Reactor\ Area\ (m^2)\ x\ Operating\ time\ (hr)} \quad (2)$$

Combustion Zone Rate (CZR): This is the time required for the combustion zone to move down the reactor. This is computed using Equation 3

$$CZR = \frac{Length\ of\ the\ Reactor\ \ (m)}{Operating\ time\ (hr)} \quad (3)$$

Moisture Content of the fuel: The heating value of the gas produced by any type of gasifier depends at least in part on the moisture content of the feedstock. The moisture content of the wood on the wet and dry basis is computed using Equation 4a and 4b

$$MC_{wet} = \frac{\text{Wet weight(g)} - \text{Dry weight(g)}}{\text{Wet weight(g)}} \text{ x } 100 \quad (4a)$$

$$MC_{dry} = \frac{100 \text{ x } MC_{wet}}{100 + MC_{wet}} \quad (4b)$$

Volatile Matter Content of the Fuel: The volatile matter content of the wood is calculated by crushing the wood samples to grain, 2g of the grain samples was thereafter placed in porcelain crucible which was also placed on hot plates at a temperature of 600°C to drive off the volatiles with a little opening provided. The heating continued until the flame coming out through the holes have ceased. This indicates that all volatile matters have been driven off. After this, the weight of each of the heated samples was taken and the percentage of volatile matter content was calculated using Equation 5.

$$\%V = \frac{W_{33} - W_{34}}{W_{33}} \quad (5)$$

Where: %V = Percentage of the volatility for wood by weight; W_{33} is the Weight of the wood before placing on hot plate; W_{34} is the Weight of the wood after placing on hot plate

Ash Content: The ash content test of the fuel samples was carried out by crushing the samples and accurately weighed 2g in a porcelain crucible or local clay pot with a lid. The samples were heated to temperature of 600°C on a hot plate. After two hours, the weight of the samples was taken and the ash content was calculated using Equation 6.

$$Ash_c = 100 - \frac{(W_{33} - W_{34})g}{W_{33}}\ x\ 10 \quad (6)$$

Where: W_{33} is the Weight of the wood before placing on hot plate; W_{34} is the Weight of the wood after placing on hot plate

Fixed Carbon: The value of the fixed carbon percentage (% C) is computed using Equation 7
% C = % Moisture + % Volatility + % Ash_c) - 100% (7)

RESULTS AND DISCUSSION

Table 1 gives the results obtained from the performance evaluation of the fabricated gasifier system and the proximate analysis of the wood used as biomass in the gasifier. This analysis gives the suitability of the feedstock for use in a particular application, this include moisture content, volatile content, fixed carbon and ash content in the wood. The moisture content of the feedstock was reduced by sun drying to obtain a high gasification temperature, which results in the high-energy values obtained. The result reveals the abundant biomass energy potentials available in the feedstock considered. Table 2 presents the summary of the ultimate analysis of the wood and the heating values. The ultimate gives the weight percentage of carbon, hydrogen, nitrogen, oxygen and Sulphur. The results of the ultimate analysis were used to obtain both higher and lower heating values of the biomass considered. Theses heating values show that the abundant energy potentials in the feedstock for various applications as heating and small scale power generation.

Table 1: Gasifier Performance and Proximate Analysis of Wood Results

Parameter	Value
Performance Evaluation of the Gasifier	
Start-up Time (mins)	75
Operating Time (mins)	10
Weight of Wood Used (kg)	4.3
Fuel Consumption Rate (kg/hr)	25.29
Specific Gasification Rate (kg/m^2-hr)	815.9
Combustion Zone Rate (m/hr)	5.9
Proximate Analysis of the Wood	
Moisture Content (%)	45.9
Volatile Content (%)	85
Ash Content (%)	20
Fixed Carbon (%)	50.9

Table 2: Ultimate analysis of the wood used

Synthetic gas produced	Value
Carbon (C) in %	18.9
Nitrogen (N_2) in %	0.58
Hydrogen (H_2) in %	2.74
Oxygen (O_2) in %	11.88
High Calorific Value (kj/kg)	8409.65
Low Calorific Value (kj/kg)	7807.45

Performance Test Carried Out on the Updraft Gasifier: The quantities of wood fed into the gasifier during the performance testing are weight. At the beginning of the test after fire has been introduced into the reactor, white smoke was observed to be emitted, after some time, the gasifier started to produce a brown smoke which is the indication of the combustible gases been formed. During this time, the brown smoke was ignited and gradually the production of the combustible gases began to be noticed through the production of yellow flame at the outlet of the gasifier at about 75 minutes for the wood and continued until the experiment lasted. The colour of the produced flame indicating the production of synthetic gases and the energy content in wood correspond to the tests carried out by Yinesor (2008) and Ojolo *et al.,* (2012) on wood chips.

Conclusion: This research has explained the design, fabrication and performance operation of a laboratory updraft gasifier which has the capacity to produce gas from common biomass like rice husk, wood, palm kernel shell and so on with wood as fuel. The gasifier volume was designed to hold enough biomass and can run for at least 85 minutes without refueling. The proximate and ultimate analyses of the fuel were obtained from the test carried out. Synthetic gases were noticed to be produced after ignition and combustion take place. The results obtained revealed that there contain some substantial energy content in the wood which is available to be used for meeting the present energy challenges.

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